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A Scheme of Downlink HARQ Scheduling in TDD LTE-A

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Abstract: In order to provide a higher peak data rate, carrier aggregation (CA) is implemented into Long Term Evolution Advanced (LTE-A) systems. However, more and more downlink hybrid automatic repeat request (HARQ) feedback information need to be transmitted. Especially, in time division duplexing (TDD) systems must comply with the updownconfig, the complexity and storage of HARQ scheduling increase largely under CA. In this paper, a HARQ scheduling scheme is proposed which is based on dynamic information tables to generate and schedule the downlink feedback information of acknowledgment/negative acknowledgment (ACK/NACK) in Long Term Evolution Advanced (LTE-A) system. Some storing tables based on component carriers are designed and a dynamic updated scheme is proposed, which reduces the scheduling complexity and memory occupation effectively.

Keywords: Automatic Repeat Request (HARQ), Carrier Aggregation (CA), Long Term Evolution Advanced (LTE-A)

1. Introduction

With the developing of the carrier aggregation (CA) technique, the Long Term Evolution Advanced (LTE-A) system can support up to five component carriers (CCs), one is called Pcell and the others are called Scell. In the case of CA, each uplink subframe needs to generate feedback bits for each component carrier [1]. HARQ, namely Hybrid Automatic Retransmission request, is such a technology which combines FEC (Forward Error Correction) and ARQ (Automatic Repeat request) at the transmitter and/or receiver [2]. According to 3GPP [3], HARQ in DL is asynchronous (hence non-persistent), while in UL it is synchronous. For group allocation, HARQ retransmissions are allocated individually in an asynchronous way in downlink (DL), and individually and synchronously in uplink (UL). In this paper, we focus on DL HARQ. Acknowledgment/negative acknowledgment (ACK/NACK) feedback information sent on the *n th* UL subframe is associated to the physical downlink shared channel (PDSCH) or the physical downlink control channel (PDCCH) released by semi-persistent scheduling (SPS) within the downlink (DL) subframes $n-k_i(\mathrm{i}=1,2,\ldots\mathrm{M})$, where the value of $k_i \in K$ is shown in table 1 [4]. Based on those feedback information, eNodeB decides whether to retransmission the data which have been sent in last $n-k_i(\mathrm{i}=1,2,\ldots\mathrm{M})$ subframes. From table 1, the number of k_i in a set K is denoted as M. Therefore, the obtained control information and feedback bits related with all M DL subframes all need to be stored and processed for the feedback in *n th* UL subframe.

Table 1. *DL association set index* $K:\{k_0,k_1,\cdots k_{M-1}\}$ *for TDD.*

UL/DL Configuration	Subframe n									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	-	-	6	-	4	-	-	6	-	4
1	-	-	7, 6	4	-	-	-	7, 6	4	-
2	-	-	8, 7, 4, 6	-	-	-	-	8, 7, 4, 6	-	-
3	-	-	7, 6, 11	6, 5	54	-	-	-	-	-
4	-	-	12, 8, 7, 11	6, 5, 4, 7	-	-	-	-	-	-
5	-	-	13, 12, 9, 8, 7, 5, 4, 11, 6	-	-	-	-	-	-	-
6	-	-	7	7	5	-	-	7	7	-

This paper investigates the acknowledgment/negative acknowledgment (ACK/NACK) feedback for CA in LTE-A TDD, which is very challenging because the number of HARQ feedbacks that need simultaneous feedback increases linearly with the DL/UL subframe ratio and number of CCs. What's more, the potential large UL/DL asymmetry and limited transmit power in UL According to [4], when the UL/DL configuration is set to 5 in the case of 5 CCs, the maximum number of DL HARQ processes can reach 75. Each process needs to obtain and record all of the HARQ parameters and ACK/NACK feedback bits within all $n-k_i(\mathrm{i}=1,2,...\mathrm{M})$ DL subframes, so the large storage and huge complexity of the feedback scheduling become a large hurdle in LTE-A. The bundled DTX feedback and a novel A/N bundling scheme based on the Combined Component Aggregated HARQ A/N [5, 6, 7] is proposed in [8, 9] to reduce the number of feedback bits. [10] gave a new PUCCH resource allocation to shorten feedback latency. [11] analyze the HARQ RTT to implement DL asychronous HARQ. [12] investigates HARQ buffer management by leveraging information-theoretic achievability arguments based on random coding, which can obtain an available HARQ on-chip buffer and reduce power consumption. But how to generate and schedule the feedback scheme is often neglected.

In this paper, an efficient feedback scheme is proposed based on a dynamic information table, the size of which is less than 5×5×13. All of the HARQ parameters and feedback bits of all CCs are all included in the information table, and some simple updates need to be implemented every subframe. As a result, it reduces the scheduling complexity and memory occupation effectively.

2. System of Feedback

The generation of the HARQ information in n*th* subframe needs the values of V_{DAI}^{UL} *or* $W_{DAI}^{UL}, V_{DAI,c}^{DL}, U_{DAI,c}^{DL}$, which are decoded from the PDCCH according to Table 1 in $n-k$ DL subframes. V_{DAI}^{UL} or W_{DAI}^{UL} is the value of the Downlink Assignment Index (DAI) in Downlink Control Information (DCI) format 0 or 4 detected by UE, which represents the number of DL subframes with PDSCH transmissions and with PDCCH indicating DL SPS release within all the subframes $n-k_i(\mathrm{i}=1,2,...\mathrm{M})$. $V_{DAI,c}^{UL}$ is the DAI detected by UE in DCI format 1/1A/1B/1D/2/2A2/2B/2C. $U_{DAI,c}^{DL}$ stands for total number of PDCCH (s) with assigned PDSCH transmission (s) and PDCCH indicating downlink SPS release detected by the UE within the subframe (s) $n-k_i(\mathrm{i}=1,2,...\mathrm{M})$ [4]. All of the above parameters and their subframes detected by UE should be stored. Since the related $n-k_i$ subframes are varied per subframe. Especially some feedback bits are referred to the subframe before last in case of $k_i>10$ in table 1, which lead to distinguish their frame numbers. The effective scheduling and small storage scheme for HARQ is crucial for LTE-A system.

At first, the size of tables is designed as follows. The number of information tables is maximum of 5, which is decided by the number of CCs. Each table contains five rows, which includes the ACK/NACK feedback bits, V_{DAI}^{UL} or W_{DAI}^{UL}, $V_{DAI,c}^{DL}$, $U_{DAI,c}^{DL}$ and task-type indicates of a DL subframe. The value of task-type indicates whether there is HARQ feedback information in a UL subframe by 0 or 1.

The number of columns in the information tables is set according to the value of $k_i \in K$ in table 1. The information table is set to 10 columns when the UL/DL configuration is 0, 1, 2 or 6. Otherwise it is set to 11, 12, 13 corresponding to UL/DL configuration with 3, 4, 5, respectively. Each column stores information in a same subframe and the first 10 columns correspond to the subframes numbered as 0 to 9 in sequence.

The second, dynamic updated and scheduling scheme for HARQ feedback is discussed and the detailed steps are as follows:

Step 1: The storage of information tables are allocated for each CC based on the number of CCs and their UL/DL configurations, and then jump to one of the following steps according to the subframe number.

Step 2: When the current subframe is a DL subframe (denoted as $n-k_i$) except subframe 9, the information carried by PDCCH and PDSCH for each CC should be detected. Then the corresponding information table is updated as follows.

Step 2-1: If no PDCCH can be detected, skip to step 3, otherwise obtain the parameters of $V_{DAI}^{UL} or W_{DAI}^{UL}, V_{DAI,c}^{DL}$ by decoding of PDCCH.

Step 2-2: Look up the $k_i \in K$ in n*th* UL subframe in table 1. When one of $k_i \in K$ is less than 10, then store or update the parameters of $V_{DAI}^{UL} or W_{DAI}^{UL}, V_{DAI,c}^{DL}$ in the $(n+1)th$ column of information table. Otherwise, store or update the related Parameters in the 11*th* column. Obtain the value of task-type based on the PDSCH detection. If the value of task-type equals to 1, $U_{DAI,c}^{DL}$ and task-type of the same column as above should be updated as $U_{DAI,c}^{DL}+1$ and 1 respectively, which correspond to n*th* UL subframe.

Step 2-3: The feedback bits of ACK/NACK for the current DL subframe (denoted as $n-k_i$) are generated according to the decoding of PDSCH. When k is less than 10, store the feedback bits of ACK/NACK in the $(n-k_i+1)th$ column; when $k_i>10$, store the feedback bits of ACK/NACK in the k_i th column.

Step 3: If the current subframe number equals to 9 and the UL/DL configuration is 3, 4, 5, the parameters of $V_{DAI}^{UL} or W_{DAI}^{UL}, V_{DAI,c}^{DL}$ and task-type in the third column will be replaced by those in the 11*th* column, the ACK/NACK feedback bits in column 2, 1, 10 will be replaced by those in column 11, 12, 13, respectively.

Step 4: When the current subframe is UL subframe (denoted as n), get the related parameters from the information table of each CC, and then combine the feedback information of HARQ-ACK. The details are as follows:

Step 4-1: Look up the value of task-type from the tables of each CC in the (n+1)*th* column. If it equals 0, there is no HARQ-ACK feedback information and nothing to do. Otherwise clear the value of task-type, then read the ACK/NACK feedback bits referred to the current subframe from the information tables in all the columns of $n-k_i+1$ according to table 1. Then clear all the feedback bits and the parameters of $V_{DAI}^{UL} or W_{DAI}^{UL}, V_{DAI,c}^{DL}, U_{DAI,c}^{DL}$ in the column of $(n+1)$.

Step 4-2: Generate the final feedback information of HARQ-ACK according to the feedback bits of ACK/NACK, then send the feedback information in the UL subframe via the physical uplink control channel (PUCCH) or the physical uplink shared channel (PUSCH).

3. Specific Example

An specific example is proposed in this section with two CCs configured. The uplink and downlink configuration of the Pcell is set to 2 while the configuration of Scell is set to 4. Besides, the format 3 of PUCCH is not configured for the two cells. As a result, two information tables are generated according to section 2. The value of k_i in set K in table 1 for the Pcell is less than 10, the first information table of the Pcell is arranged into 5 rows and 10 columns, while the max value of k_i in set K in the second information table is 12, so the information table of the Scell has 5 rows and 12 columns. The structures of information tables, which are referred to it for Pcell and Scell respectively, are shown in Figure 1 to Figure 3.

According to table 1, in the Pcell, the values of $k \in K$ referred to UL subframe 2 are equals to 8, 7, 4 and 6 respectively. Assumed PDCCHs is detected in all of DL $n-k$ subframes, we should update the first information table at each of the four DL subframes in sequence as Figure 1. All of the parameters in last 4 rows are updated in the $(n+1)th$ (i.e. 3th) column. The ACK/NACK feedback bits are stored in the $(n-k_i)th$ (i.e. 5, 6, 7 or 9 th) columns in first line. If all of DL $(n-k_i)$ subframes should get feedback with ACK, the results can be seen in first row of Figure 1.

In the Scell, the values of $k_i \in K$ referred to UL subframe 2 are equals to 12, 11, 8 and 7 respectively. Assumed PDCCHs have been detected in all of DL $n-k_i$ subframes, we should update the second information table at each of the four DL subframes in sequence as Figure 2. All of the parameters in last 4 rows are updated in the $11th$ column. The ACK/NACK feedback bits are stored in the nth column in first row when k is equal to 12 or 11, otherwise the ACK/NACK feedback bits are stored in the $(n-k_i)th$ (i.e. 5or 6th) columns when k_i is equal to 8 or 7. If all of DL $(n-k_i)$ subframes should get feedback with ACK, the results can be seen in first row of Figure 2.

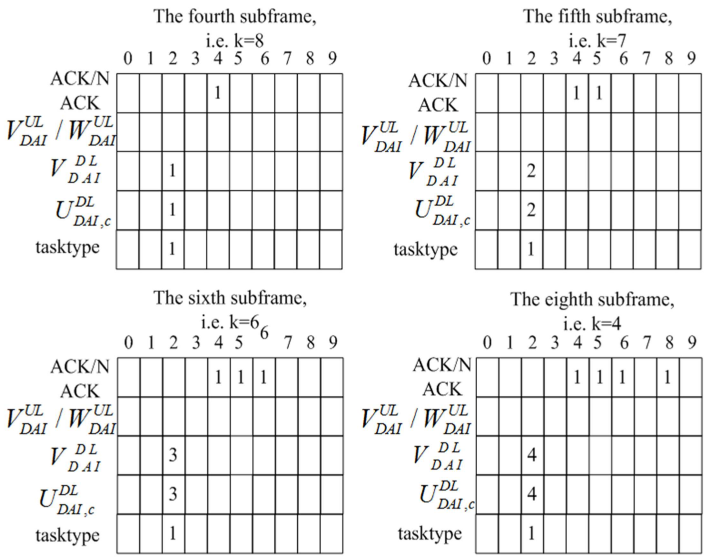

Figure 1. *The storing or updating of the related parameters for Pcell.*

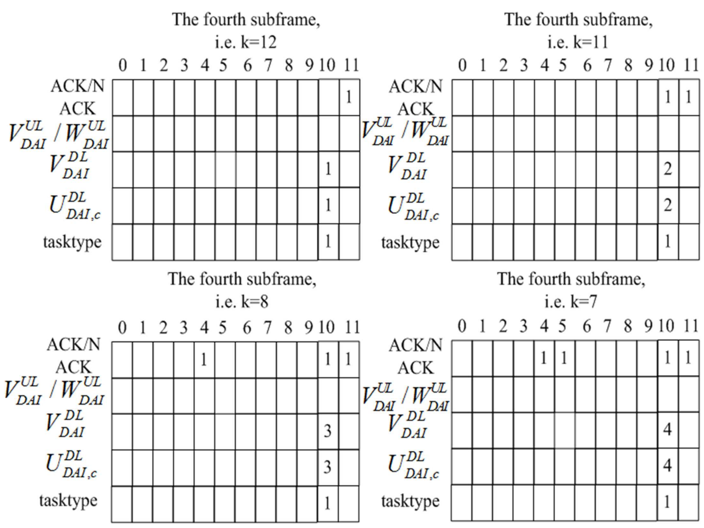

Figure 2. *The storing or updating of the related parameters for Scell.*

When the current downlink subframe is 9, for the Scell, the parameters of $V_{DAI}^{UL} or W_{DAI}^{UL}, V_{DAI,c}^{DL}, U_{DAI,c}^{DL}$ in the third column will be replaced by the parameters in the 11*th* column. The feedback bits in the columns numbered 0 and 1 will be replaced by the information in the columns numbered 10 and 11 respectively, which can be seen in Figure 3.

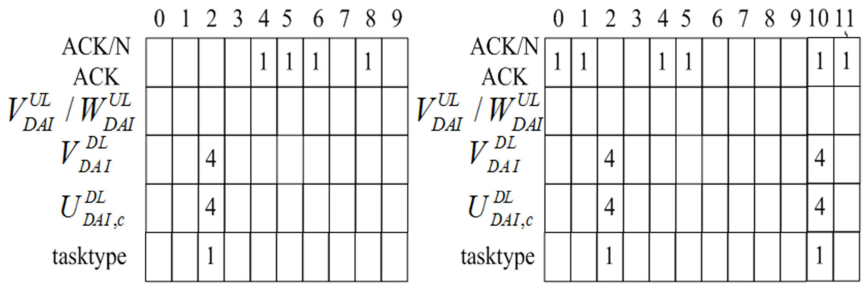

Figure 3. *The table update in subframe 9 for Scell.*

When the current downlink subframe is 2, look up the values of task-type in the 3rd column from two information tables. Both of them equals to 1, it means both of the two carriers need to be feedback with ACK/NACK. Hence we should gather the parameters of $V_{DAI}^{UL} or W_{DAI}^{UL}, V_{DAI,c}^{DL}, U_{DAI,c}^{DL}$ and the feedback bits of HARQ-ACK from two tables, and then generate and send the final information of HARQ-ACK carried by PUCCH or PUSCH according to [4]. Finally, the values of task-type are cleared in tables.

4. Summary

The scheduling of HARQ within LTE-A becomes more complicated within CA [13]. In this paper, the timing relationship and required parameters of feedback ACK/NACK are studied analyzed. An scheme of downlink HARQ scheduling scheme based on checking information tables is proposed. The required parameters are stored in tables and updated timely according to their timing relationship. As a result, the complicated scheduling problem can be completed by the table update and look-up, which reduces the processing complexity and memory occupation effectively. Further a specific example with the proposed scheme is described in detail.

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